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Introduction

The focus of our work has been toward understanding how intracontinental deformation occurs and what are the processes and physical parameters that control the rates and styles of deformation. This work has required both the selected regions and numerical analyses of processes and phenomenon thought to occur.

Underlying our work has been the presumption that two entirely different processes resist deformation in continents. One obviously is the strength of material, which depends upon the constituent minerals, the ambient temperature, and perhaps other properties such as the presence of water. The second is gravity, for to build mountain ranges or to thicken the crust work must be done against gravity. Our work has addressed both of these aspects in different ways, but in all cases we have tried to isolate them from one another. The logic here has been that it is better to isolate specific phonemena and understand them than to try to include simultaneously too many processes and not understand which are important.

In summarizing our work, let us begin with a review of studies addressing specific mechanical aspects of deformation, then consider studies of deformation and of the structure of specific areas in light of these ideas.

Mechanical Aspects of Continental Deformation

Obviously stronger rock requires greater stress to deform and is less likely to deform than weaker rock. The heterogeneous distributions of active tectonics and of relief in Asia imply normal lateral variations in the strength of the lithosphere, and Molnar and Tapponnier (1981) argued that older (less recently deformed) crust was less susceptible to deformation when India collided with Eurasia, because older crust tends to be colder than younger crust.

One major difference between continental tectonics and plate tectonics is that crustal thickening is important only in continents. Concurrent with such thickening, the mantle lithosphere should thicken, but such thickening should, in turn, induce large horizontal temperature gradients that can convectively destroy such a lithospheric root. Houseman et al. (1981) carried out a series of numerical experiments to examine this process and concluded that the initial temperature structure of mantle lithosphere might be restored only a fewto 10-20 Ma after crustal thickening began. Such a reheating of the mantle lithosphere beneath thickened crust is likely to make it hot and weak.

One important manifestation of crustal thickening is that the high elevations and thick crustal root store gravitational potential energy that can be extracted during later crustal thinning. As a result, thrust faulting and crustal thickening on the margins of mountain belts can occur simultaneously with normal faulting and crustal extension at high altitudes (Dalmayrac and Molnar, 1981).

Deep Structure of Asia

A major effort was devoted toward determining the deep structure of high plateaus and of mountain chains to determine both the extent to which the crust is thick and the degree to which the mantle is hot. We focussed on the Himalaya and Tibet.

The crust of Tibet is indeed very thick (Chen and Molnar, 1981a), but several arguments suggest that the upper mantle is quite hot (Chen and Molnar, 1981a; Lyon-Caen, 1986; Molnar and Chen, 1984). Surface wave dispersion cannot be accounted for with crust thinner than 55 km, and together with measured Sn velocities, a thickness of 70 $\pm$ 5-10 km seems required. S-wave delays from Tibetan earthquakes, however, are large, and they imply a thick zone of low velocities beneath Tibet. A careful study of Sh phases recorded at regional distances (Lyon-Caen, 1986) proves that this low velocity zone must underlie the upper 250 km of the mantle beneath Tibet. Hence, it seems likely that convective processes have removed a thickened lithospheric root beneath Tibet.

A brief study of the high plateaus of Iran and Turkey suggests that they too are underlain by hot material (Chen et al., 1980).

A convective process beneath Tibet might reveal itself in the structure of the Himalaya. Gravity anomalies can be explained by a simple model in which the Indian plate is flexed down beneath the Himalaya and loaded by the weight of the Himalaya, only if an additional force acts on that plate (Lyon-Caen and Molnar, 1983, 1985). That force seems most likely to be due to convective downwelling of the leading edge of the Indian plate, which induces a bending moment in the plate just north of the Himalaya.

A similar analysis for the underthrusting of the Tamir Basin beneath the Kunlun (Lyon-Caen and Molnar, 1984) does not require an additional force, but it too calls for a substantial amount of underthrusting beneath the range.

Deformation

Using synthetic seismograms, we have studied the faulting associated with earthquakes in two areas. Earthquakes in the Himalaya seem to occur on the top surface of the Indian plate as it is underthrust, intact, beneath the Himalaya (Baranowski et al., 1984). Hence, the Himalaya seem to comprise a giant crystalline nappe scraped off the leading edge of the Indian plate.

Earthquakes in Tibet consistently indicate east-west extension of the plateau. Moreover, these events occur either at very shallow depths in the crust or in the uppermost mantle. Hence, they seem to define a zone of low strength in the lower crust, a zone that could decouple upper and lower crustal deformation.

Reviews

We have periodically written review articles to summarize our work at various stages. Molnar and Chen (1982) summarized the seismic evidence for differences in how mountain ranges are built in different regions, and more recently Molnar and Lyon-Caen (1988) considered a number of different physical processes in mountain belts. Chen and Molnar (1981b) briefly summarized data on the structure of Tibet and Molnar (1988) more recently wrote a comprehensive review of the deep structure of the Himalaya, Tibet and the Karakorum. In addition, summaries, both at a technical level (Molnar, 1984) and at a popular level (Molnar, 1986a) have been written on the tectonic evolution of the Himalaya. Finally, a paper in Scientific American (Molnar, 1986b) gives a simple interpretation of the results of our work and that of others.

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